

Switches Faults Analysis of Voltage Source Inverter (VSI) Using Short Time Fourier Transform (STFT)

N. S. Ahmad¹, A. R. Abdullah², N. Bahari³, M. A. A. Hassan⁴

Abstract – Three-phase voltage source inverter (VSI) play a very important role in the present industrial life. The knowledge and information about faults characteristic of the VSI is important to prevent failure of equipment, data losses, high maintenance and economic losses. Therefore, to insure a continuous and safety operation of the VSI, switches faults analysis implemented to prevent further damages and the commonly open and short circuit faults are happened within the VSI. This paper present the analysis of switches faults VSI by using linear time-frequency distribution (TFD) which is short time Fourier transform (STFT) by simulation using MATLAB. STFT are appropriate technique to analyze non-stationary that consist of multi-frequency component and magnitude that represent signal in time-frequency representation (TFR). From the TFR obtained, parameters of the signals are estimated such as instantaneous average current, instantaneous of root means square (RMS) current, fundamental RMS current, total harmonics distortion (THD), total nonHarmonics distortion (TnHD) and total waveform distortion (TWD). According the analysis of switches faults parameters VSI is presented. Based on the signal parameters, characteristic of signal are calculated. The end of research, various characteristics of parameter VSI faults are clearly differentiate between open and short switches faults. The information of analysis switches faults is usefull to industrial application in the process for identifying fault detection and can fault can be identify early. **Copyright © 2014 Praise Worthy Prize S.r.l. - All rights reserved.**

Keywords: Voltage Source Inverter, Short Time Fourier Transform, Time-Frequency Distribution, Time-Frequency Representation, Root Means Square, Total Harmonics Distortion, Total nonHarmonics Distortion, Total Waveform Distortion

Nomenclature

STFT	Short Time Fourier Transform
FFT	Fast Fourier Transform
TFD	Time Frequency Distribution
TFR	Time Frequency Representation
VSI	Voltage Source Inverter
RMS	Root Mean Square
THD	Total Harmonics Distortion
TnHD	Total Nonharmonics Distortion
TWD	Total Waveform Distortion
$x(\tau)$	Input Signal
$w(t)$	Analysis Window

I. Introduction

The reliability of power electronics equipments becomes extremely important in industrial applications.

These industrial applications include machine tools, conveyors, pumps, centrifugal machines, presses, elevators and packaging equipment [1]-[4].

However, faults can occur at large power electronics and can be dangerous inclusive causing a breakdown of a process.

So, the analysis faults in power electronics have become mature technology in recent years to prevent very costly shut-downs because of faults in industrial manufacturing facilities.

Many techniques were presented by various researcher for analyze VSI faults. Such as, [5] that used Fast Fourier Transform (FFT) to analyzed current spectrum for detecting the characteristics of an open transistor. While, also used wavelet transform for examined information about the fault signatures for detection and classification fault [6]. Nevertheless, Fourier analysis does not represent temporal information and wavelets have high time resolution for high frequency component and high frequency resolution for low frequency component.

To overcome this problem, short-time Fourier transforms (STFT) that used to analysis switches faults at VSI. This paper present time frequency distribution (TFD) which is STFT for analyze the characteristic of VSI faults include of open-circuit and short-circuit fault for the upper and lower fault. STFT represent parameter estimated in time frequency representation (TFR). From TFR, parameter such as instantaneous average current, instantaneous of root means square (RMS) current, instantaneous of fundamental RMS current, total harmonics distortion (THD), total nonHarmonics

distortion (TnHD) and total waveform distortion (TWD) are estimated [7]. Based on result, characteristic of VSI faults are calculated.

II. Voltage Source Inverter System

In this paper, the model of VSI is designed a three phase as indicated in Fig. 1. A three phase inverter is supplied from Gate Pulse Generator. This inverter modulates the input DC voltage to variable frequency AC output according to the pulse width modulation [8]-[10].

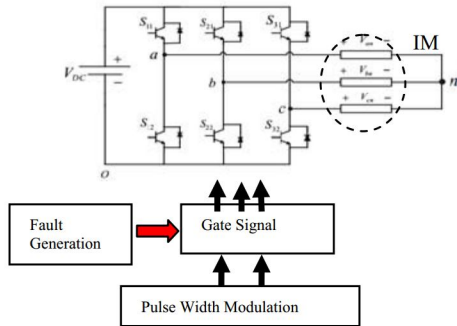


Fig. 1. The model of Voltage Source Inverter

There are following three modules in the Simulink modeling of VSI as shown Fig. 1. They are as follow:

- **Gate Signal:**

Gate signal module is used for generation of gate pulse for switching of six inverter switches. It done by comparing three sine pulse with a triangular wave as shown Fig. 1.

- **Pulse Width Modulation:**

The PWM is done where V_{tri} is common triangular wave which is compared with three control sines pulse and relative phase difference of 120 degree with each other.

- **Fault generation:**

The module of fault generation is used for give pulse at switching gate signal. It has duration for give pulse depends on duration fault in VSI system.

In power electronics faults occurring can be generally classified into open-circuit and short-circuit faults. Based on Figs. 2 and 3 show the model of VSI circuit when both of faults. The open-circuit faults may be caused by the lifting of the bonding wires due to the thermal cycling, a driver failure, or a short-circuit fault-induced rupture. Besides that, the open-circuit fault will not cause the immediate shut down of whole system, and the inverter can still work in an abnormal but steady situation. Moreover, the abnormal state resulting from an open-circuit fault can lead to overstresses on the healthy switches as well as pulsating currents. This can in turn lead to failures of other components. The Fig. 3 show the T1 open and current cannot flow, so open-circuit fault occur in this case. The short-circuit fault where this faults leads to catastrophic failure of the inverter if the other transistor of the same inverter leg is turned-on, this resulting in a direct short-circuit of the dc-bus link.

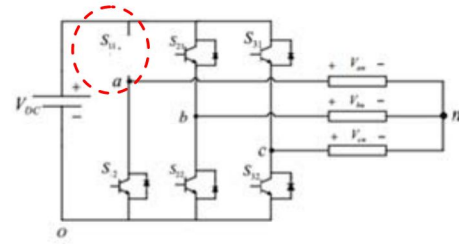


Fig. 2. The model of Voltage Source Inverter (Open-Circuit)

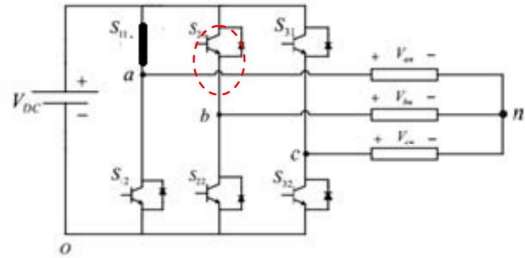


Fig. 3. The model of Voltage Source Inverter (Short-Circuit)

To prevent the short circuit fault, it is necessary to minimize possible elapsed time after the fault occurred [11]-[14]. Based on Fig. 3 that show T1 is short, so short-circuit fault occur in this case.

III. Time Frequency Analysis

A time-frequency analysis, which represents the time change of a signal, is significant in all fields. The time-frequency analyzing techniques are known Wigner distribution, a short time Fourier transform (STFT), a kernel method, and a characteristic function method etc.

In this paper, time-frequency representations (TFD) are used to analyze or characterize signals whose energy distribution varies in time and frequency.

One of technique such as STFT is used for time-frequency analysis of non-stationary signals, where the use of Fourier transform alone becomes inadequate. STFT is widely used in power quality analysis [15], which has a better frequency resolution, but has very limited analysis of transient signals STFT decomposes the time varying signal into time-frequency domain components; hence it provides an insight in the time-evolution of each signal component.

STFT signal is divided into small segments and signal is assumed as stationary in these segments. These segments are called window. This method that obtained localization of Fourier analysis can perform transformation by selecting appropriate window at desired place [16]. Appropriate window must be used in STFT. The important factor is level of change in signal spectrum to determine the most appropriate frame length [16], [17]. So, changing parameter of signal can be observe depend on selected appropriate window length.

A rectangular window leads to a poor frequency resolution. Also used window size effects obtained frequency resolution. Large window size increase frequency resolution by reducing time resolution, on the

contrary small window size reducing frequency resolution by increasing frequency resolution. Specially signal spectral analysis of non-stationary signals need capable functions in time and frequency resolution [16]-[18]. Based on equation below, the input signal define $x(\tau)$ and $w(t)$ as analysis window:

$$S(t, f) = \left| \int_{-\infty}^{\infty} x(\tau) w(\tau - t) e^{-j2\pi f\tau} d\tau \right| \quad (1)$$

IV. Parameter Estimation

Parameters of the faults signal are estimated from the TFR to identify the characteristics of the signal.

These parameters are instantaneous of average current, instantaneous of root mean square (RMS) current, instantaneous RMS fundamental current, instantaneous total waveform distortion (TWD), instantaneous total harmonics distortion (THD), instantaneous total interharmonics distortion (TnHD) [7], [19], [20].

V. Results

The results of simulation presented are based on the parameter below as shown Table I. That consider of dc supply, carrier frequency (Hz), IGBT and fundamental frequency (Hz). From simulation, the result of open-circuit and short-circuit faults for upper and lower switches has been analyze and calculate all characteristic of parameter.

TABLE I VOLTAGE SOURCE INVERTER SPECIFICATIONS	
Parameter, unit	Value
DC supply, V	50
Carrier frequency, Hz	5kHz
Snubber resistance	1×10^5
Internal resistance	1×10^6
Fundamental frequency	60Hz

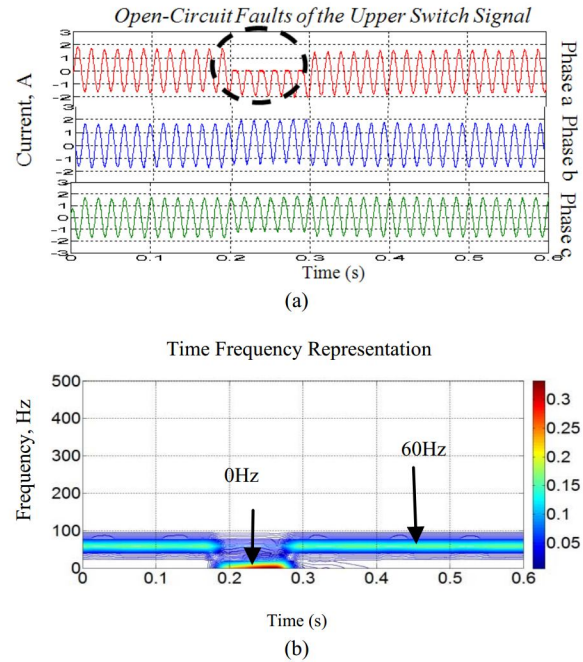
A. Open-Circuit Faults of the Upper Switch Signal

The signal currents of open-circuit faults upper switch with three-phase are shown Fig. 4(a).

Qun-Tao An [21] also observe the signal for open-switch faults in inverter without sensors to improve the reliability of power electronic system. Phase a represent red color while for phase b and c represent blue and green color, respectively. In this case, the VSI current discontinuity for phase a at 0.2 to 0.3 s and has a dc component. For phase b and c, we can see all the phase currents are continuous are represents by Fig. 4(a).

Fig. 4(b) shows TFR with three dimensions the horizontal axis represent time, vertical axis is frequency and third dimension indicating the amplitude of a particular frequency at a particular time is represented by the color of each point. of the signal that represent fundamental of signal is 60 Hz and other harmonics at dc component which is 0 Hz starting 0.2 to 0.3 second.

The similarly contour are represent for different type fault which open-circuit lower, short-circuit upper and short-circuit lower. It is because it contain for same temporal spectral and magnitude.



Figs. 4. Result of Open-Circuit Faults of the Upper Switch Signal
(a) Open-circuit fault of the upper switch signal
(b) Time Frequency Representation

Figs. 5(a) and (b) show the instantaneous average current and instantaneous RMS current that represent in per unit (pu) where current phase a is lower while phase b and c, respectively, is greater between 0.2 to 0.3 second.

For the instantaneous RMS fundamental current, phase a is lower than 0.8 and phase b and c, respectively is higher than 0.8 as shown Fig. 5(c).

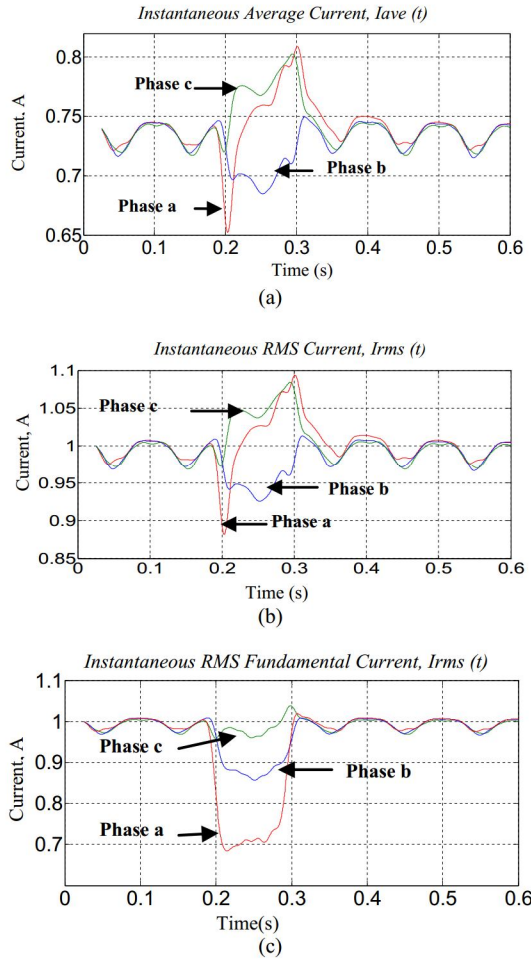
Therefore, the instantaneous total waveform distortion (TWD) for phase a gives 1.45% from 0.2 to 0.3s but phase a and b is gives 1.09%. as shown in Fig. 6, but the value of instantaneous of total harmonics distortion and total non-harmonics distortion, respectively is zero percent cause this signal have dc component.

B. Open-Circuit Faults of the Lower Switch Signal

As seen in the Fig. 7 shows the result of analysis open-circuit faults lower switch signal. The fault occurs at 0.2 to 0.3 s at phase a after 0.3s signal is sinusoidal shape.

The other researcher also analyze the IGBT's in open fault condition to know the information by Kattela Ganesh. We can observe that there is a discontinuity at 0.2 to 0.3 s when faults occurs at switch IGBT1 but phase b and c is a continuity in the operation.

From TFR, the characteristics are seen in Fig. 8 where the instantaneous average current, instantaneous RMS current and instantaneous RMS fundamental current has been estimated.



Figs. 5. Characteristic of Parameter (a) Instantaneous Average Current, $I_{ave}(t)$, (b) Instantaneous RMS current (pu), (c) Instantaneous RMS fundamental current (pu)

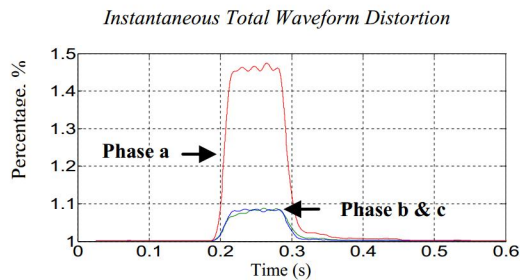


Fig. 6. Instantaneous total waveform distortion

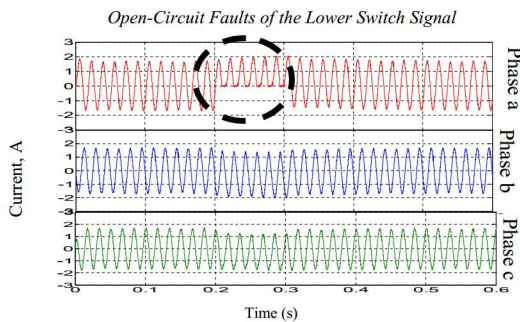
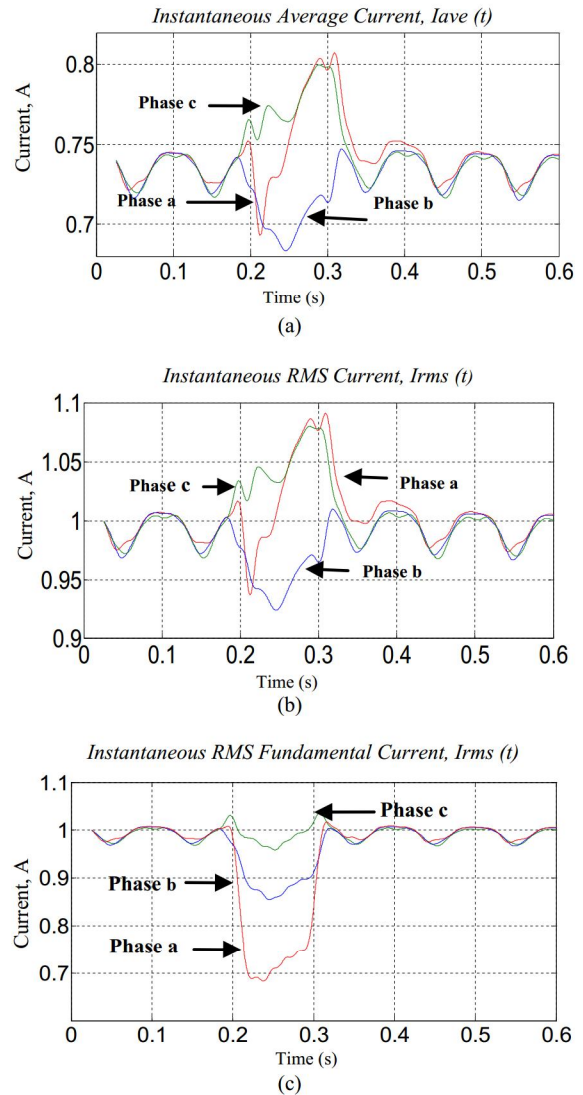


Fig. 7. Result of open-circuit faults of the lower switch signal

The current for average and RMS at phase a is greater than phase b but higher than phase c as shown in Figs. 8(a) and (b). Lastly, the RMS fundamental current represent phase a is momentary decrease is 0.7A but phase b and c above than 0.7A.



Figs. 8. Characteristic of Parameter, (a) Instantaneous Average Current, $I_{ave}(t)$, (b) Instantaneous RMS current (pu), (c) Instantaneous RMS fundamental current (pu)

Besides that, analysis of instantaneous total waveform distortion as shown Fig. 9. From the observation, TWD for phase a gives 1.45% and phase b and c is 1.09%.

Since the fault signals only occur at dc component, the instantaneous of THD and TnHD is zero percentage.

C. Short-Circuit Faults of the Upper Switch Signal

During short-circuit fault, the current phase a momentary increase when fault occur at 0.2 to 0.3second, while phase b and c, respectively is momentary decrease as shown Fig. 10. Figs. 11(a) and (b) show the analysis of characteristic short-circuit faults at upper switch in term of average current and RMS current when current phase a is greater than phase b and c.

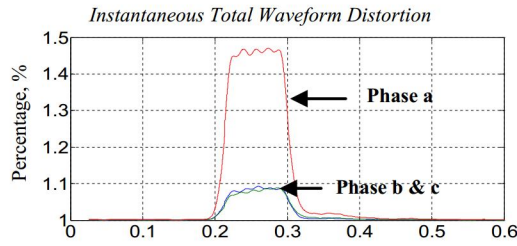


Fig. 9. Instantaneous Total Waveform Distortion

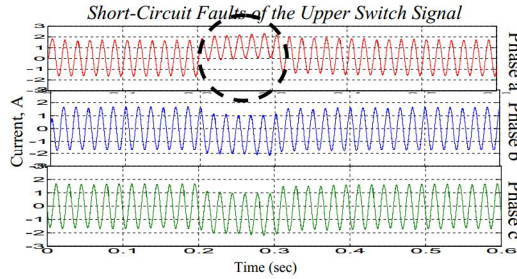
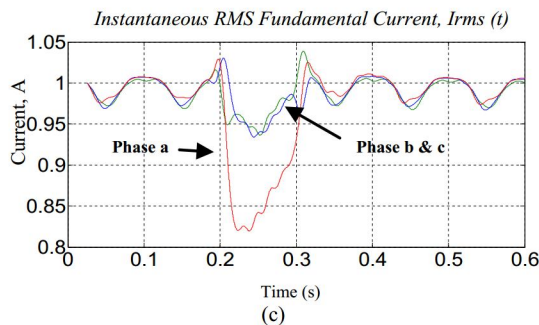
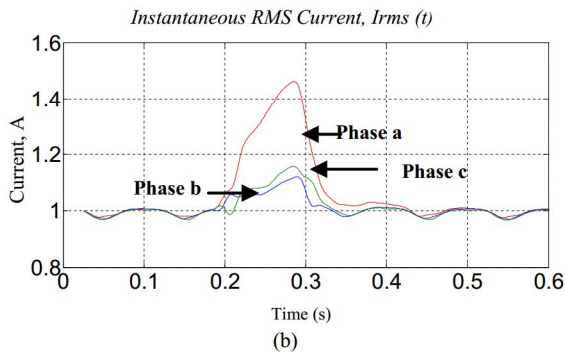
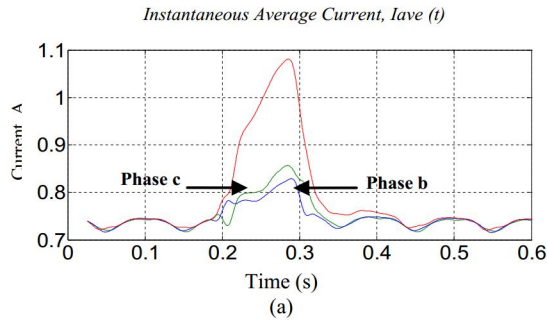


Fig. 10. Result of Short-Circuit Faults of the Upper Switch Signal



Figs. 11. Characteristic of Parameter, (a)Instantaneous Average Current, $I_{ave}(t)$, (b) Instantaneous RMS current (pu), (c) Instantaneous RMS fundamental current (pu)

Also observe characteristic of RMS fundamental current, phase a is lower than phase b and c, then respectively is same condition gives 0.1s as shown Fig. 11(c). Besides that, from the observation of total waveform distortion the value of TWD gives 1.6% and unbalanced waveform for phase a and phase b and c, respectively is 1.18% based on Fig. 12. In this analysis, instantaneous of total harmonics distortion and total non-harmonic distortion is zero percentages.

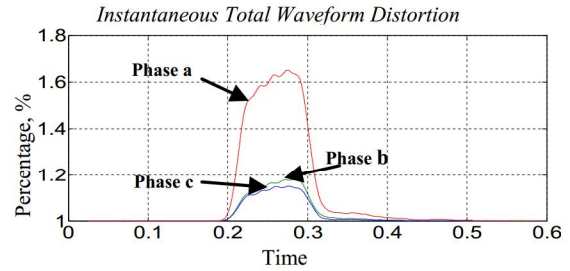


Fig. 12. Instantaneous Total Waveform Distortion

D. Short-Circuit Faults of the Lower Switch Signal

Signal current for phase a is momentary decrease when short-circuit faults at lower switch as shown Fig. 13. The signal show across zero axis starting from 0.2 to 0.3 second but phase b and c is increase at the same time.

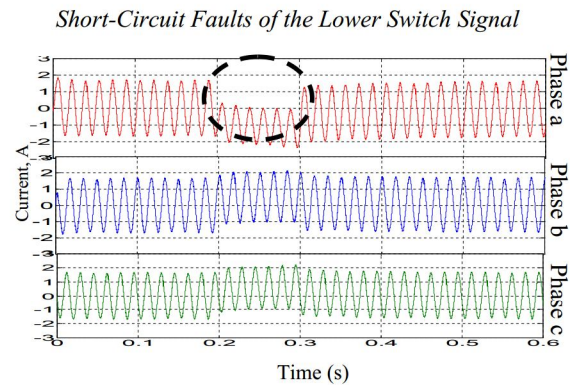


Fig. 13. Result of Short-Circuit Faults of the Lower Switch Signal

From the observation of instantaneous average current and instantaneous RMS current, the current phase a is greater while phase b and c, respectively is lower.

As show in Figs. 14(a) and (b), we can see more detail about characteristic of each phase current. The Fig. 14(c), current at phase b and c is same but phase a is lower than 0.5 second.

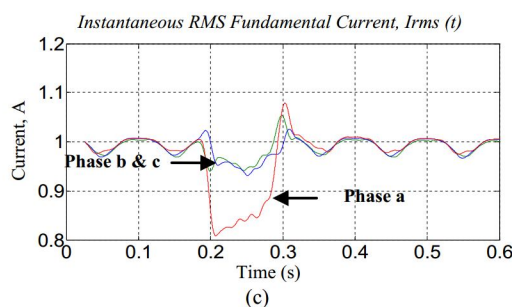
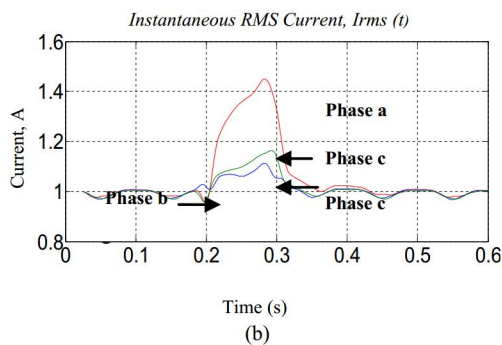
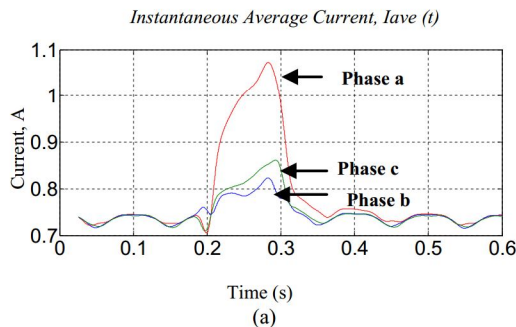
From the observation about the analysis of short-circuit lower, the value of TWD gives 1.6% but phase b and c, respectively, is 1.18% and 1.19% between 0.2 until 0.3s.

Besides that, the value for THd and TnHd is zero percent because these signals only occur at dc component as shown Fig. 15.

Table II shows the summary of characteristic of VSI during fault occurs. The characteristic for each fault is important for observation fault in VSI.

TABLE II
SUMMARY OF CHARACTERISTIC VSI

Parameter	Type of fault	Observation
Average Current	Open Upper	$I_a < I_b < I_c > 0$
	Others	$I_a > I_b > 0$
	Short	$I_a = I_b > 0$
	Others	$I_a \neq I_b > 0$
	Short Lower	$I_a > I_b > I_c > 0$
	Others	$(I_a > I_b > I_c) \neq$ Short Lower
RMS Current	Open Upper	$I_a < I_b < I_c > 0$
	Open Lower	$I_a > I_b < I_c > 0$
	Short	$I_a > I_c > I_b$
IRMS Current	Short	$I_b = I_c > 0$
	Other	$I_b \neq I_c > 0$



Figs. 14. Characteristic of Parameter, (a) Instantaneous Average Current, $I_{ave}(t)$, (b) Instantaneous RMS current (pu), (c) Instantaneous RMS fundamental current (pu)

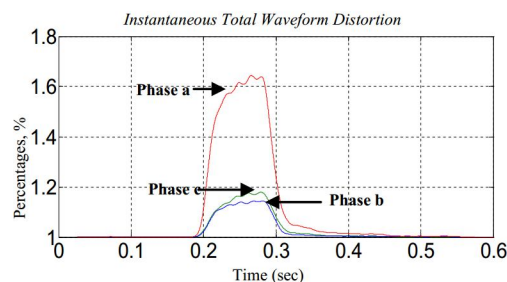


Fig. 15. Instantaneous Total Waveform Distortion

VI. Conclusion

The fault characteristics are important evaluation for the VSI system. In this paper, the fault characteristics based on power switches failures for upper and lower are presented, analyzed by using short time Fourier transform. The possible faults for power switch such as IGBTs and diodes including open-circuit faults and short-circuit faults which mainly focus on the distortions to input current at inverter. Here, we get the better and clear understanding of the fault severity and also exact time, frequency and magnitude of the fault simultaneously. Analysis of the system using STFT is a better to a performing VSI fault analysis.

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Authors' information

Faculty of Electrical Engineering, UniversitiTeknikal Malaysia Melaka.



Nur Sumayyah Bt Ahmad was born in Terengganu, Malaysia, on November 6 on 1988. She received B. Eng. degrees with honours in electrical engineering from the UniversitiTeknikal Malaysia Melaka (UTeM) on 2012. Currently, she is a master degree student researcher in electrical engineering at UniversitiTeknikal Malaysia Melaka (UTeM).



Dr. Abdul Rahim Abdullah was born in Kedah, Malaysia on 1979. He received his B. Eng., Master, PhD Degree from University of Technology Malaysia in 2001, 2004 and 2011 in Electrical Engineering and Digital Signal Processing. He is currently a Senior Lecturer and Coordinator of Center of Excellent Robotic and Industrial Automation (CeRiA) in UniversitiTeknikal Malaysia Melaka (UTeM)



Norhazilina Bt Bahari was born in Melaka, Malaysia. She received her Master Engineering in Electrical Engineering (Power), UTM and completed her Bachelor Engineering degree in Electrical Engineering at UTeM. She is currently a lecturer at UniversitiTeknikal Malaysia Melaka (UTeM)



Mohd Arif Bin Abu Hassan was born in Kelantan, Malaysia, on January 26 1988. He received B. Eng. degrees with honours in electrical engineering from the University TeknikalMalaysia Melaka (UTeM) on 2012. Currently, he is a master degree student researcher in power driver in electrical engineering at UniversitiTeknikal Malaysia Melaka (UTeM).